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FOR

A PHOTOGRAMMETRIC APPARATUS

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TECHNICAL FIELD

This invention relates to a photogrammetric apparatus for use in a wide variety applications that include, among others, surveying, engineering, architectural, crime and accident scene investigation, quality assurance, nondestructive testing, structural deformation analysis, and similar applications that can benefit from improved photogrammetric data capture and analysis techniques.

BACKGROUND OF THE INVENTION

In the various pertinent industries, including for purposes of illustration but not limitation, surveying, those with skill in the art have long-recognized the need for an improved system and method for utilizing non-professional or less skilled personnel (for example, individuals other than high-salary, certified surveyors, who may have limited availability) to accurately gather geophysical, configuration, and arrangement information of, for example, land, buildings, and off-road and roadside utility equipment. In the past, gathering of such information traditionally required extensive knowledge of geometry, surveying, and engineering to ensure that the information obtained was accurate with respect to equipment and asset identification and configuration, as well as to geographic location and arrangement.

Gathering information in the field is a labor-intensive process with the potential for large margins of error, which can result in expensive and time-consuming duplication of effort to correct mistakes. In the present day information age, many attempts have been made to improve the state of the art of such information gathering efforts by incorporating modern technology.

Yet even today it is common to see a traditional two or three man survey crew along the roadside manually gathering information about land, buildings, and electric and communications utilities, often times scribbling hand written notes or attempting to manually enter information into laptop computers. The quality of the information gathered by such survey crews varies with the geographical conditions, weather, the time of day, and the skill of the surveyors.

After gathering the needed information, the survey crew often then returns to the office and turns over the information gathered to a separate group of surveyors, or engineers, for analysis. The in-office analysis is a difficult process because the office personnel must then decipher the notes and data collected by the field crew and tabulate the data into a computer system. The surveyors, or engineers, in the office often need several meetings with the field crew to ensure that they are accurately interpreting the collected data. These meetings are further necessitated by the fact that the office personnel rarely actually view the locations from which the collected information was obtained. As a result, the field crews are often required to incur several return trips to gather corrected and additional information that is required for the office analysis.

In the noted example of the surveying profession, surveyors and engineers alike have recognized the value of photographs in the analysis of field information. While photographs can often eliminate the need for return visit to the field site, the survey crew must still explain to the office personnel the location and significance of each photograph. Even still, the process remains very inefficient since inaccurately recorded photograph angles, locations, and related data can induce unexpected and unverifiable errors into the analysis process.

Many prior art attempts have been made to advance that state of the art of surveying equipment and to minimize the inefficiencies inherent in the process of gathering information in the field and in conducting office analysis. For example, in U.S. Pat. No. 6,194,694 to Shirai, sighting telescopes and auto-focusing systems have been added to traditional surveying equipment. However, educated surveyors or technicians are still required to operate the equipment since the techniques for use require higher educational and technical knowledge.

The need remains for an apparatus that provides a single, comparatively untrained worker to accurately collect and conveniently store field data for subsequent analysis in the office. Frequently the desired data takes the form of information that can be gathered from an object substantially located in a single plane within a field of view. For example, an architect may need to obtain the exterior dimensions of a building from the planar images of each side thereof. In a further example, engineers need to collect utility pole data such as pole height, pole diameter, the height of attachments such as electrical and communications cables, transformers, and similar information. Ideally this information would be collected and stored for later analysis back in the office without the need for complicated in field set up and breakdown of measuring equipment for each location to be identified and analyzed.

Prior art apparatus and methods for collecting accurate information in the field have been complicated, costly, and not adapted for ease of use by a single operator, who may not have training in the field of, for example, surveying. Such prior art apparatus and methods involve the technical field of photogrammetry. The field of photogrammetry has been dominated by highly trained individuals and complex computer systems and software that require the use of two images of the same object from different locations that are then overlaid and analyzed to

compute coordinates of unknown points in the image. For example, as in U.S. Pat. No. 6,310,644 to Keightley, two tower mounted camera assemblies, or a single camera with a beam splitter, are used to create a three-dimensional coordinate system from at least two photographs. Similarly, U.S. Pat. No. 6,304,669 to Kaneko et al. is limited to the use of two photographs of the target object from different locations to produce a survey map. Additionally, U.S. Pat. No. 5,216,476 utilizes two stereo cameras to create three-dimensional coordinate systems.

What continues to be missing from the technical field of photogrammetry is a solution to the need for inexpensively gathering field information while ensuring accuracy and ease of retrieval, as well as improved computer analysis capabilities that do not require highly trained individuals to operate or expensive budgets for high-performance equipment. While many of the prior art devices aimed to improve these attributes in the art of such devices, none has achieved an optimized capability in an easy to use form that is readily suited to application in the myriad industries that have demonstrated a need for analysis of field gathered data and photogrammetric information.

What has been needed but heretofor unavailable in the prior art devices and methods, is a low-cost, user friendly, photogrammetric apparatus for determining distances between substantially coplanar points in a single image. The term coplanar used herein refers to the conventional use in the context of geometric applications, which is distinguished from the specialized use of "coplanar" in the context of stereo photogrammetry techniques. The use of the geometric term coplanar herein aids in the description of points in the single image photogrammetric techniques as employed according to the principles of the present invention. The most preferable photogrammetric apparatus would be compatible for use in wide-ranging

applications including, but not limited to, architecture, engineering, surveying, crime and accident scene investigation, quality assurance, nondestructive testing, deformation analysis, among many other situations that require accurate, low-cost analysis of data that can include, for example, substantially coplanar points in a single image of a field location.

The present invention meets these and other needs without adding any complexity, inefficiencies, or significant costs to implementation in existing applications and environments. In fact, the preferred photogrammetric apparatus according to the present invention can be implemented with relatively low-cost measurement and computer components that can be adapted according the to the principles of the present invention. The various embodiments of the present invention disclosed are readily adapted for such preferred ease of manufacture, low fabrication and setup costs, and compatibility with off the shelf components.

SUMMARY OF INVENTION

In its most general configuration, the present invention advances the state of the art with a variety of new capabilities and overcomes many of the shortcomings in new and novel ways. In one of the many preferable configurations, the photogrammetric apparatus incorporates, among other elements, a storage device for receiving and storing information in a database gathered from a plurality of other elements in the apparatus.

In one of many variations of the instant invention, that apparatus includes an image capturing device having a imager, such as a digital camera, that captures images and automatically stores the images in the database. The database is also adapted to simultaneously receive and store data from a bearing finding device, a range finding device, and an azimuth

finding device. The bearing finding device preferably collects and communicates to the database information regarding a heading to which the image capture device is pointing. The range finding device similarly collects and transmits to the database information regarding a distance of a target object from the image capture device. The azimuth collection device collects and saves to the database an angle of the image capture device axis from vertical.

A further variation of any of the preceding embodiments may also further include an angle measurement means for obtaining angles other than azimuth angles that may be needed for measurements in non-vertical target object applications. Therefore, in place of the azimuth collection device used on approximately vertical target objects, the angle measurement means is adapted to collect and transmit to the database information regarding the orthogonal distance from the image capture device to the non-vertical target object.

Any of the preceding configurations and embodiments may also be adapted to include a global positioning system (GPS) device to collect and store to the database a geophysical location of the image capturing device when the image was captured.

The present invention also further preferably includes an image processor configured to analyze the images and data stored in the database. In one of the many preferred capabilities and routines of the image processor, a calibration routine is adapted to determine a focal length of the image capturing device in a pixel unit of measure using points in the captured image. The preferred routine utilizes a calibration image of a real-world calibration target containing a plurality of target indicia that establish a pattern of points and or geometric relationship having known, predetermined distances and arrangements. The calibration routine is further adapted to account for a radial optical distortion inherent in the lens of the image capture device. Upon

image capture, the calibration routine can analyze the target indicia of the calibration image. The calibration compares the imaged target indicia with the known, predetermined distances and relationships and to measure the distance between the target indicia in a corresponding pixel unit of measure. From this information, the image processor and calibration routine determines a set of scale ratios of the real distances between the target indicia to the pixel unit of measure distances on the image. This is accomplished for a plurality of the target indicia, and the results are then averaged into an average scale ratio, which is then used to calculate a calibrated focal length in pixel units of measure for the image capturing device.

The calibrated photogrammetric apparatus also includes a measurement routine that accepts inputs from a user viewing the captured and processed image of at least two points in the image that are substantially coplanar on the real world target of interest. As described above, the term "coplanar" as used herein has a specialized meaning in the context of the instant invention. The measurement routine is configured to retrieve data from the storage device database and to determine a distance between the points using the calibration date set and a series of trigonometric calculations. The measurement routine may be used to measure the distance between points on substantially coplanar objects or other, different points in the image. For example, the distance between various points on a substantially coplanar utility pole may be calculated. More specifically, the point can correspond to cables or equipment on the pole. In similar fashion, the amount of sag in a conductor between such poles can also be calculated.

Additional routines of the image processor are included in the present invention that are configured to calculate a number of geometric relationships between selected elements in the image. Such relationships may determine, for purposes of example without limitation, a

diameter and a circumference of a substantially planar substantially cylindrical object in the image. For instance, the operator may select a point in the image on each side of the cylindrical object for the measurement routine to determine the distance between the points. The routine can calculate the diameter of the cylindrical object at any point on the object from the image. The point of the desired diameter does not have to be on an image axis. The measurement routine calculates a diameter point image scale for use in calculating the diameter when it is not on the image axis. This routine enables the user to determine the largest and smallest diameter along a substantially cylindrical object that actually tapers. With the diameter known, a myriad of other calculations may be performed including, for instance, a circumference calculation, a surface area calculation, and a volume calculation. In addition to the cylindrical objects, an area and a perimeter of all planar geometric shapes may be easily calculated. From this information, various other data and relationships may be derived, including volumetric and mass data.

The image processor may also include a global positioning system ("GPS") coordinate routine adapted to establish the geophysical coordinates of a target object. This routine utilizes the actual geophysical location of the photogrammetric apparatus and or image capture device in conjunction with the captured and processed image and database information to determine a translated coordinate set that establishes the GPS coordinate set of the target object. This aspect of the present invention is unique in that it enables the user to remotely safely locate and analyze target objects using a single image of the target that may be directly inaccessible without exposing personnel to undue risk of harm or significant inconvenience or exertion.

The physical configuration of the photogrammetry apparatus may take a number of configurations. In one preferred configuration the image capture device, the storage device and

database, and the bearing, range, azimuth, and global positioning system coordinate finding devices are all contained in a single housing that may be, for example, only slightly larger than a current day digital camera. The housing may include a high speed data transmission port that can be easily joined to a traditional computer system, similar to the universal serial bus (USB) joining and transmission methods of modern digital cameras. The computer system may contain a second database similar to the storage device database for receiving the information from the apparatus as well as the image processor. The computer system facilitates the use of various data input devices such as a keyboard and a mouse to enter data and a monitor to view the images and data. Further variations of the present invention include configurations for use with a personal digital assistant, a laptop computer, and other transportable processing and input devices for on-site analysis of the collected data.

In yet another configuration, the apparatus may include a transportation means such as a backpack to house majority of the apparatus with an external image capture device. Such configuration enables the use of a reduced size image capture device and enables the user to complete other tasks without interference of the apparatus. In a further variation, the image capture device is attached to an adjustable bracket secured to a construction type hard hat, or other safety helmet. In this configuration, the image capture device can be easily aligned with an eye when in use and rotated out of the line of sight while performing other tasks. A remote initiation button may be used with any of the described embodiments.

In variations of the preceding configurations, the enclosure material and construction of the photogrammetric apparatus is selected to be a impact resistant and durable material that resists abrasion wear and that can withstand exposure to severe weather and deleterious fluids

and substances, such as, without limitation, biological, and industrial fluids and substances. Some such exemplary substances and fluids include steam, high temperature water, cleaning fluids, petrochemicals, biological fluids, oil, grease, bacteria, fungi, insects, pests, and raw and prepared agricultural food stuffs, to name a few.

The enclosure may also include any number of surface textures in a non-slip gripping surface including, for example, work and grip surfaces that are also formed to have stipple and or dimple patterns of raised portions. Further, the enclosure may include a plurality of connection points for safety straps and other securing means.

More specifically, any of the preceding embodiments may include a plurality of expansion ports for integration of a plurality of external devices such as date and time recordation devices, GPS devices, temperature and humidity measuring devices, wind speed and direction measuring devices, barometric pressure measuring devices, altitude measuring devices, dosimeters, modems, wireless data transmission devices, emergency signal transmitters, two-way radios and printers.

These variations, modifications, and alterations of the various preferred embodiments may be used either alone or in combination with one another as can be better understood by those with skill in the art with reference to the following detailed description of the preferred embodiments and the accompanying figures and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Without limiting the scope of the present invention as claimed below and referring now to the drawings and figures, wherein like reference numerals and numerals with primes across

the several drawings, figures, and views refer to identical, corresponding, and or equivalent elements, features, components, and parts:

FIG. 1 is an elevation view, in reduced scale, of a photogrammetric apparatus according to the present invention and configured to capture an image of a cylindrical object;

FIG. 2 is a functional block diagram of the photogrammetric apparatus illustrated in FIG. 1 and according to the present invention;

FIG. 3 is a plan view, in reduced scale, that describes the various angles, dimensions, and reference points identified with the calibration and measurement devices and routines of the photogrammetric apparatus according to the present invention;

FIG. 4 is a functional block diagram of the calibration device and process according to the present invention;

FIG. 5 is an elevation view, in reduced scale, of the various angles, dimensions, and reference points identified in connection with the detailed description of the photogrammetric apparatus according to the present invention;

FIG. 6 is a functional block diagram of the measurement device and routine according to the present invention;

FIG. 7 is a block diagram of the diameter and circumference measurement device and routine according to the present invention;

FIG. 8 is a block diagram of the target object GPS coordinate measurement device and routine according to the present invention;

FIG. 9 is a plan view, in reduced scale, of the various angles, dimensions, and reference points identified in the detailed description of the diameter and circumference measurement and device routine of the photogrammetric apparatus according to the present invention; and

FIG. 10 is an elevation view, in reduced scale, of the various angles, dimensions, and reference points identified in connection with the detailed description of the additional capabilities of photogrammetric apparatus according to the present invention.

Also, in the various figures and drawings, the following reference symbols and letters are used to identify the various angles, dimensions, objects, and arrangements of elements described herein below in connection with the several figures and illustrations: A, B', b, β_s, $\Delta\beta_A$, $\Delta\beta_R$, C', C1, C2, c, DA, DM, DH, D', d, E, e, F, f, f_A, fp, G, G', g, H', H1, H2, H3, h, IA, IP, P, P_A, P_R, p_c, P1, P2, R, , RS, SP1, SP2, S, V_A, V_R, and W.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The photogrammetric apparatus according to the present invention demonstrates a significant step forward in the field of single image photogrammetry. Many ineffective and unsuccessful attempts have been made to create a photogrammetric apparatus having the convenience and efficiency of the present invention. The preferred photogrammetric apparatus practiced with the principles of the instant invention has wide application for architecture, engineering, surveying, facilities management, and investigation professionals, who have long sought a light, durable, high automated, and easily transportable photogrammetric apparatus that can be easily cleaned, stored, and transported at the conclusion of the work period with minimal effort and inconvenience. The preferred configurations and described alternatives,

modifications, and variations of the photogrammetric apparatus of the instant invention overcome prior shortcomings and accomplish new and novel solutions to the prior art problems with vastly improved configurations and arrangements of inventive elements that are uniquely configured, and which demonstrate previously unavailable capabilities.

With reference now to the accompanying figures and specifically to FIGS. 1 and 2, in one of the many preferable arrangements, the photogrammetric apparatus **100** includes an image capturing device **120** having an imager **130**, such as a digital camera, that captures images and automatically saves the images to a storage device with a database **110**. The storage device and database **110** simultaneously receive and store data from a bearing **140** finding device, a range **150** finding device, and an azimuth **160** finding device. Each of such devices may be separate components, or may be combined into a single physical unit for convenience.

The bearing finding device **140** is adapted to collect and send to the storage device database **110** information regarding a heading to which the image capture device **120** is oriented. The bearing finding device **140** may take the form of a plurality of devices, however it is preferably a digital compass, such as, for illustration purposes without limitation, a solid-state, magnetic flux gate compass.

The range finding device **150** collects and saves to the storage device database **110** information regarding a real distance of a target object from the image capture device **120**. While the range finding device **150** may utilize any number of widely known distance measuring devices, it is preferably a laser range finder.

The azimuth collection device **160** collects and saves to the storage device database **110** an angle of the image capture device **120** axis from an imaginary vertical line. The azimuth

collection device **160** is preferably an inclinometer, but may configured with any number of equally suitable devices and technologies.

A further variation of any of the preceding embodiments may also further include an angle measurement means for obtaining angles other than azimuth angles that may be needed for measurements in non-vertical target object applications. Therefore, in place of the azimuth collection device used on approximately vertical target objects, the angle measurement means is adapted to collect and transmit to the database information regarding the orthogonal distance from the image capture device to the non-vertical target object. The angle measurement means may incorporate elements as simple as a right angle square, as used by carpenters, to physically ensure that the apparatus **100** is aligned orthogonal to the non-vertical target, or elements as sophisticated as object image recognition software that inform the user when the target image is aligned orthogonal to the non-vertical target object. A plurality of additional measurement means varying from the simple square to the sophisticated software may be used with the present invention.

Any of the preceding configurations and embodiments may also be adapted to include a global positioning system (GPS) device **170** configured to communicate to the storage device database **110** a geophysical location of the image capturing device **120** at about the time when the image was captured.

The photogrammetric apparatus **100** may take a number of physical configurations. In one preferred configuration the image capture device **120**, the storage device and database **110**, and the bearing **140**, range **150**, azimuth **160**, and GPS coordinate **170** finding devices are all contained in a single housing **175** slightly larger than a modern digital camera. The housing **175**

includes an expandable external device port assembly **180** that may include high-speed data transmission ports and expansion ports for integration of a plurality external devices. The expandable external device port assembly **180** may provide two way data transmission between a plurality of external devices, including for example computer systems, date and time recordation devices, GPS devices, temperature and humidity measuring devices, wind speed and direction measuring devices, barometric pressure measuring devices, altitude measuring devices, dosimeters, modems, wireless data transmission devices, emergency signal transmitters, two-way radios and printers.

The preferred photogrammetric apparatus **100** and included computer system may also preferably contain a second database similar to the storage device database for receiving the information from the apparatus as well as the image processor. The computer system facilitates the use of various data input devices. For example, input devices such as a keyboard, a mouse, a trackball, a digitizer, and a headset may be used to enter data and a monitor to view the images and data. Further variations of the present invention include configurations for use with a personal digital assistant, a laptop computer, and other transportable processing and input devices for on-site analysis of the collected data.

The apparatus **100** may be secured to a mounting device **185**. The mounting device **185** may include a tripod or any adjustable support device. In yet another configuration, the apparatus **100** may include a transportation means such as a backpack to house majority of the apparatus **100** with an external image capture device **120**. Such configuration enables the use of a reduced size image capture device **120** and enables the user to complete other tasks without interference of the apparatus **100**. In a further variation, the image capture device **120** is attached

to an adjustable bracket secured to a construction type hard hat, or other safety helmet. In this configuration, the image capture device **120** can be easily aligned with an eye when in use and rotated out of the line of sight while performing other tasks. A remote initiation button **105** may be used with any of the described embodiments.

In variations of the preceding configurations, the housing **175** material and construction of the photogrammetric apparatus **100** is selected to be a impact resistant and durable material that resists abrasion wear and that can withstand exposure to severe weather and deleterious fluids and substances, such as, without limitation, biological, and industrial fluids and substances. Some such exemplary substances and fluids include steam, high temperature water, cleaning fluids, petrochemicals, biological fluids, oil, grease, bacteria, fungi, insects, pests, and raw and prepared agricultural food stuffs, to name a few.

The housing **175** may also include any number of surface textures in a non-slip gripping surface including, for example, work and grip surfaces that are also formed to have stipple and or dimple patterns of raised portions. Further, the housing **175** may include a plurality of connection points for safety straps and other securing means.

Now referring to FIGS. 3 and 4, the calibration device and routine is adapted to determine an actual distance per pixel value, taking into account radial distortion, as well as a focal length of the image capture device in units of pixels. The calibration process begins with the capture of an image of a calibration target that includes at least two calibration indicia having a predetermined and known geometric relationship. The calibration image should preferably be captured at an angle orthogonal to the capturing device image axis "**IA**" indicated in FIG. 5.

Many processes for calibrating image capture devices to account for distortions in the image have been developed over the years. Virtually all of the calibration methods use essentially the same parameters including camera position, camera orientation, lens focal length, lens radial distortion, pixel array size, and the optical axis location.

One embodiment of the present invention utilizes an efficient device and method to account for radial distortion. Referring again to FIG. 3 and FIG. 4, the calibration target **200** may be configured in a number of ways with various target indicia **205**. The calibration target **200** should extend across the full range of the object that is to be imaged. For example, if the apparatus is used to capture images and data from a plurality of utility poles that are approximately 25-30 feet tall, then the calibration image would ideally be approximately 30-35 feet. Such a calibration target can easily be created by utilizing an exterior wall of a building to mount target indicia **205**.

An exemplary configuration may use 0.5 centimeter square target indicia **205** located in pairs separated by four to six feet horizontally across the length of the desired target. At least three pair of target indicia **205**, mounted at points **B'**, **C'**, **D'**, **E'**, **G'**, **H'**, are desired such that a pair is approximately at each extremity of the image and a pair is approximately at the center of the image, refer to FIG. 3.

A further embodiment of the calibration target **200** may include a lightweight mat with uniformly spaced target indicia **205**. The mat may be constructed of a lightweight plastic or fabric that can be easily folded or rolled. The mat is preferably several hundred feet long, approximately 2-12 inches wide, and packaged in a automatic retractable housing for convenient storage and use. The mat may include a plurality of mounting devices such as rings or hanger

devices. The mat may be easily hung from the side of a structure or set-up in a field with lightweight mounting tines that may be forced into the earth. Another embodiment may consist of essentially a rope with equally spaced target indicia **205**.

Continuing with the calibration process **208** exemplary configuration of FIG. 3, upon completion of the calibration target setup **210**, the image capturing device **120** is setup **220**. The image capturing device **120** is aligned so the axis of the imager **130** is orthogonal to the calibration target **200**. Further, the image capturing device **120** is rotated ninety degrees so the horizontally mounted target indicia **205** are parallel with the vertical image direction of the imager **130**. This process **220** ensures the image capturing device **120** is calibrated in the same orientation as the objects to be imaged, utility poles in the present example.

With the image capture device **120** setup **220** complete, a calibration image **235** is captured and saved in the storage device database **110**. One with skill in the art would recognize that a similar calibration image **235** may be captured for objects of any orientation. The calibration image **235** is captured when the user depresses the apparatus initiation button **105**. The initiation button **105** activates a plurality of devices in the apparatus **100** to collect data. However, in the calibration process the initiation button **105** only activates the image capture device **120, 230** and the range finding device **150, 240**. The distance **"F"** from the image capture device **120** to the calibration target **200** collected from the range finding device **150** is stored in the storage device database **110**. Data from the other data collection devices is not needed in the exemplary calibration process because the axis of the image capture device **120** is orthogonal to the calibration target **200**. When the apparatus **100** is not in the calibration process the depression of the initiation button **105** will initiate the capture and storage of data from all the

connected devices including, for example, the bearing finding device **140**, the azimuth finding device **160**, the GPS coordinate finding device **170**, and the plurality of integrated external data collection devices connected to the external device port assembly **180**.

Referring still to FIG. 3 and FIG. 4, the calibration process proceeds with the retrieval of the calibration image **235** and the distance **"F"** from the storage device database **110** by the image processor **190**. During the calibration process, the image processor **190** calculates a plurality of image scales **250**, an average image scale **260**, and the focal length **"f" 270** of the imager **130** in pixel units.

In the example illustrated in FIG. 3, image scales would be computed by the image processor **190** consisting of ratios of the actual distance between reference points **B'** and **C'** on the calibration target **200** to the pixel distance between the corresponding image plane **"IP"** reference points **"b"** and **"c"**. Similar image scales would be computed for reference points **D'-E'** and reference points **G'-H'**.

Another embodiment of the image processor **190** enables the user to select the target indicia **205** on the calibration image **235**. Alternative embodiments of the image processor **190** are automated to discriminate the target indicia **205** from the surroundings in the calibration image **235**. Regardless of the image processor **190** embodiment, the user will enter the actual distance between the target indicia **205** and the image processor **190** will save the data to the storage device database **110**. Once the target indicia **205** are identified, the image processor **190** will determine the pixel distances between the target indicia **205** and the plurality image scales **250**. The image processor **190** will further calculate an average image scale **260** that may then be used to assign actual distances to pixel distance. Additionally, the image processor **190** will

calculate the focal length **"f"**, **270** in pixel units by dividing actual distance **"F"** from the image plane **"IP"** to the calibration target **200** by the previously computed average image scale.

Now with reference to FIG. 5 and FIG. 6, the image processor **190** may retrieve the average image scale from the storage device database **110** for use in a measurement routine **300**. The measurement routine is typically performed in an office environment after data has been collected in the field.

Referring again to the example of surveying utility poles, an unskilled worker can easily operate the apparatus **100** by simply aiming the image capture device **120** at the target utility pole and depressing the initiation button **105**. To the user the data collection process is as easy as taking a photo. Simply depressing the initiation button **105** commands collection and storage of data from all the connected devices including, for example, the range finding device **150**, the bearing finding device **140**, the azimuth finding device **160**, the GPS coordinate finding device **170**, and the plurality of integrated external data collection devices connected to the external device port assembly **180**. For example, the user may aim the apparatus **100** at the utility pole **"P"** and depress the initiation button **105**. The range finding device **150** collects and stores to the storage device database **110** the distance **"DM"** from the apparatus **100** to the utility pole **"P"** along the image axis **"IA"**. The bearing finding device **140** collects and stores to the storage device database **110** the heading of the apparatus **100** image axis **"IA"**. The azimuth finding device **160** collects and stores to the storage device database **110** the angle "β_s" of the image axis **"IA"** from an imaginary vertical line. One with skill in the art can appreciate that alternative embodiments may measure an angle of the image axis **"IA"** from a number of other reference lines and the equations modified accordingly. For example, another embodiment may measure

the angle of the image axis **"IA"** from an imaginary orthogonal reference line. Such a modified image axis **"IA"** measurement system would be used in embodiments utilizing non-vertical target object. In a further embodiment, the GPS measurement device **170** collects and stores to the storage device database **110** the geophysical coordinates of the apparatus **100**. Skilled workers may then analyze the images and multitude of data stored in the storage device database **110**.

Referring still to FIG. 5 and FIG. 6, and the utility pole example, the first step **310** in the measurement routine is for the image processor **190** to retrieve an image and all associated data from the storage device database **110** for analysis. The second step **320** is to calculate the horizontal distance **"DH"** from the focal point "f_p" of the apparatus **100** to the pole **"P"**. The focal point "f_p" referred to herein is also commonly referred to as the perspective center "O" in the field of photogrammety. The horizontal distance **"DH"** can be calculated using trigonometric relationships between the known angle "β_s" and the known measured distance **"DM"**. Next, to calculate reference angles "$\Delta\beta_A$" and "$\Delta\beta_R$" the distances of reference points **"A"** and **"R"** from the image axis **"IA"** in pixel units must be determined **340**. The measurement routine will automatically determine pixel distances **"P_A"** and **"P_R"**. Further, with **"P_A"**,**"P_R"**, and **"f"** known in terms of pixel units, reference angles "$\Delta\beta_A$" and "$\Delta\beta_R$" may be calculated **350** using simple trigonometry. Reference angles from the horizontal **"V_A"** and **"V_R"** may be calculated once reference angles "$\Delta\beta_A$" and "$\Delta\beta_R$" are known. Finally, the actual distance between reference points **"A"** and **"R"** may be calculated **360** using **"DH"**, **"V_A"**, and **"V_R"**.

Continuing with the utility pole surveying example and referring to FIG. 10, the apparatus **100** may also be used to calculate the sag "**S**" of conductors hung between utility poles. To eliminate the need target the actual conductor, the user may place a reference stick "**RS**" directly under the lowest point of the conductor to use as a target object. Once the image and data are collected, the user simply identifies the ground reference point "G" at the base of the target, the point on the conductor substantially directly over the reference stick, and a point directly above that on an imaginary line drawn between the two utility poles from the conductor's point of attachment. The calculation of the distance between these points is then determined in the same manner previously described for substantially coplanar points.

A plurality of additional routines of the image processor calculate a number of geometric relationships between selected elements in an image. An exemplary routine calculates the diameter and circumference of substantially planar substantially cylindrical objects. This routine and device enables the user to determine the largest and smallest diameter along a substantially cylindrical object that actually tapers. Once the diameter is known, a myriad of other calculations may be performed including, for instance, a circumference calculation, a surface area calculation, and a volume calculation. In addition to cylindrical objects, an area and a perimeter of all planar geometric shapes may be easily calculated.

Referring to FIG. 6, the first step **410** in the pole diameter and circumference routine **400** is for the image processor **190** to retrieve an image and all associated data from the storage device database **110** for analysis. The second step **420** is to calculate the actual distance "**DA**" from the apparatus **100** to the pole attachment at reference point "**A**" and calculate the slope focal length to the attachment "$\mathbf{f_A}$". Once "**DA**" and "$\mathbf{f_A}$" are known, the third step **430**

calculates an image scale, which is a ratio of **"DA"** to **"f_A"**, at the reference point **"A"**. In the fourth step **440** the user selects a point at the right edge of the pole and a point at the left edge of the pole at the location that the pole diameter is desired. The image processor **190** automatically determines the distance in pixel units of measure between the selected points. The diameter of the pole at reference point **"A"** is then calculated **450** by multiplying the image scale at point **"A"** with the pixel separation distance. Lastly, once the diameter is known the circumference of the pole at point **"A"** is calculated **460** using principles of geometry. With the diameter known and the image processor's **190** ability to determine the distance between any two substantially coplanar points on the pole, a myriad of other calculations may be performed including, for instance, the surface area calculation and the volume calculation. Further, one with skill in the art can appreciate that in addition to cylindrical objects, the area and perimeter of all planar geometric shapes may be easily calculated by simply identifying the critical distances on the shape.

The image processor may also include a target object GPS coordinate routine **500**. This routine utilizes the image capture device GPS coordinates in conjunction with the other database information to calculate the GPS coordinates of the target object **510**. Using trigonometry, the routine computes the horizontal distance **"DH"** to the target object **520** using the distance measured **"DM"** from the range finding device **150** and the azimuth angle "β_s" from the azimuth finding device **160**. Next, the routine utilized the heading of the apparatus **100** in conjunction with the horizontal distance **"DH"** to compute the GPS coordinates of the target object **530**. This aspect of the present invention is unique in that it enables the user to safely determine the

geophysical location of target objects that may be inaccessible or expose a surveyor to undue risk of harm.

As represented in the various figures, the photogrammetric apparatus is not necessary shown to scale but is shown in one of many possible and equally desirable representative relative dimensional proportions, as will be apparent to those with skill in the art. For example, although the photogrammetric apparatus is shown to have a generally rectangular configuration, any of a wide variety of equally suitable 3-dimensional envelopes and profiles are available and would be compatible for purposes of and contemplated by the photogrammetric apparatus of the present invention.

Numerous alterations, modifications, and variations of the preferred embodiments, configurations, modifications, variations, and alternatives disclosed herein will be apparent to those skilled in the art and they are all contemplated to be within the spirit and scope of the instant invention. For example, although specific embodiments have been described in detail, those with skill in the art can understand that the preceding embodiments and variations can be further modified to incorporate various types of substitute and/or additional materials, component quantities, shapes, relative arrangement of elements, and dimensional and proportional configurations for compatibility with the wide variety of industrial, commercial, and professional services environments known to and available in the respective industries. Accordingly, even though only few variations of the present invention are described herein, it is to be understood that the practice of such additional modifications and variations and the equivalents thereof, are within the spirit and scope of the invention as defined in the following claims.